Synopsis of Epidemic Modeling Studies*

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Topics

- *INTRODUCTION*
- **Epidemic Modeling Overview**
- **Epidemic Modeling Example**
  - **Background Information On Smallpox**
  - **Smallpox Casualty Estimates For Scenario B**
- **Concluding Comments**

Objectives

- **Acquire Actual and, as Appropriate, "Surrogate" Epidemiological Data Sets for Smallpox, Pneumonic Plague and Hemorrhagic Fever Outbreaks**

- **On the Basis of Available Epidemiological Data,**
  - **Analytically Reconstruct Historical Outbreaks**
  - **Then Make Estimates of Potential Outbreak Casualties for New Initial Conditions and Modern Outbreak Controls**

- **Relate These Outbreak Casualty Estimates to Biological Attacks on In-Theater Military Forces**

Analytical Scope

BRIGADE, DIVISION OR CORPS DEFENSIVE MEASURES

ANALYSES	Pre-Attack Prophylaxis	Early Warning (Standoff Detection)	Trans-Attack Respiratory Protection	Prompt Identification Of BW Agent	Post-Attack Prophylaxis And/Or Therapy	Quarantine
Scenario A	NO	NO	NO	YES	YES (Early)	YES
Scenario B	NO	NO	NO	NO	YES (Late)	YES
Scenario C	NO	YES	YES	NO	YES (Late)	YES

Status of Modeling Efforts

- **Basic Semi-Empirical Approach & Ebola Hemorrhagic Fever Epidemics**
  - **Sponsor: JPO-BD with Army OTSG (LTC Carl Curling)**
  - **Technical Effort: Completed in December 1999**
  - **Published Report: "Contagious Disease Dynamics for Biological Warfare and Bioterrorism Casualty Assessments", Institute for Defense Analyses, IDA Paper P-3488, February 2000, Unclassified**
- **Smallpox Epidemics**
  - **Sponsor: DTRA/ASCO (Dr. Peter Merkle)**
  - **Technical Effort: Completed in October 2000**
  - **Draft Final Report: "Smallpox Transmission and BW Casualty Assessments," Institute for Defense Analyses, IDA Paper P-3550, October 2000, Unclassified**
- **Pneumonic Plague Epidemics**
  - **Sponsor: JPO-BD with Army OTSG (LTC Debra Schnelle)**
  - **Technical Effort: Nearing Completion**
  - **Draft Final Report: Scheduled for Delivery in May 2001**

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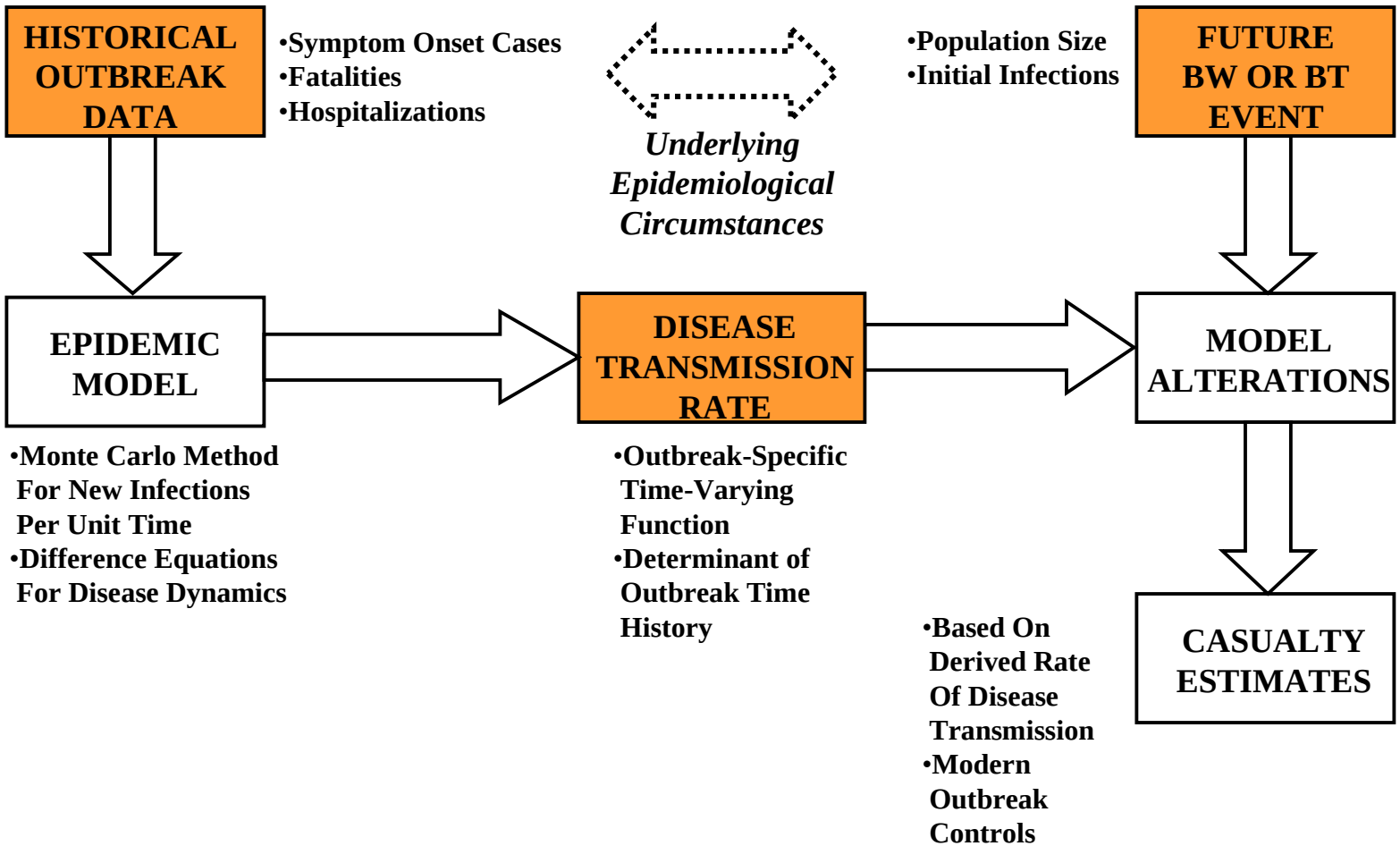
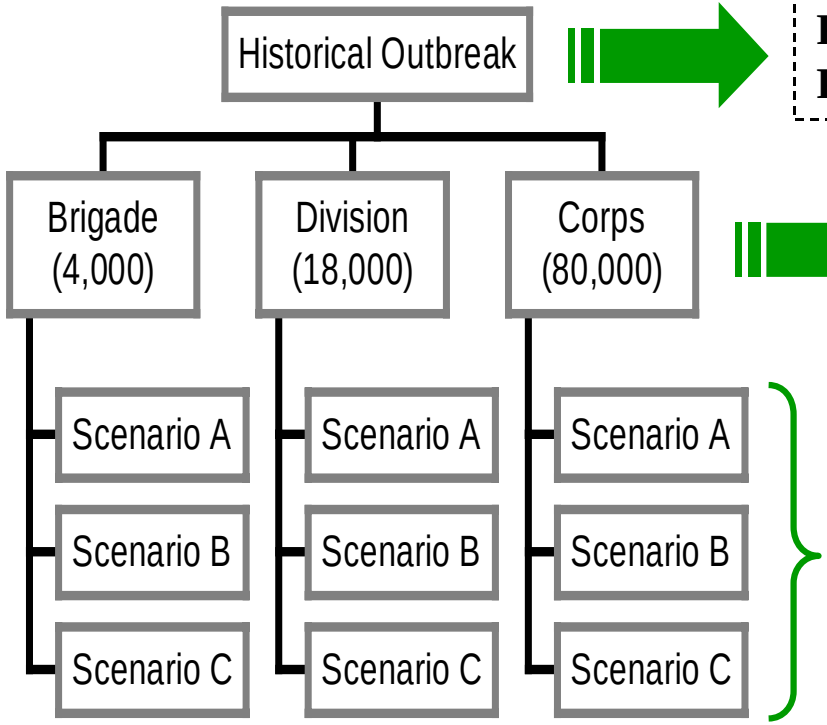
Epidemic Modeling Possibilities & Choices

POSSIBILITIES	MY CHOICES
• "First Principles"	• Semi-Empiricism
• Stochastic Framework	• Deterministic ("Mean-Field") Framework
• Spatiotemporal Spread	• Outbreak Dynamics
• "AccuWeather-Like" Predictions	• "Ball-Park" Estimates

Semi-Empirical Mean-Field Approach



Basic Elements of Casualty Estimation



Review Historical Outbreaks, Select the Most Pertinent Ones & Format Epidemiological Data

FOR EACH SELECTED HISTORICAL OUTBREAK, Derive a Transmission Rate That Reproduces the Dynamics of This Outbreak in the Population of Interest

FOR EACH POPULATION & SCENARIO,

- **Account for Future Epidemiological Circumstances by Changing Initial Conditions, by Truncating the Historically Derived Rate of Disease Transmission, and/or by Modifying the Mean-Field Algorithm**
- **Calculate the Total Number of Removals (Deaths and Recoveries) as a Function of the Number of Initial Exposures (Infections)**

Key Methodological Constraints

- **Geographical Aspects of Epidemics**
  - **IDA Modeling Efforts Do Not Involve Explicit Quantitative Analyses of Where Individuals Become Infected.**
  - **However, the Semi-Empirical Mean-Field Approach Does Have Geographical Implications**
    - **Population Density**
    - **Spatial Aspects of Historical Input.**
- **Mass Action Law**
  - **The Mass Action Law Calls for the Homogeneous Mixing of Contagious and Susceptible Individuals and It Invokes a Constant Rate of Disease Transmission.**
  - **However, Outbreak-Specific Time-Varying Rates of Disease Transmission Extend the Reach of Mean-Field Models by Accounting for Epidemiological Circumstances Like the Growth of Disease Awareness in the Populace, the Gradual Imposition of Systematic Outbreak Controls, Etc.**
- **Disease-Causing Contacts in Military Units Versus Civilian Populations**
  - **Historical Disease Transmission Rates for Civilian Populations May or May Not Capture Critical Features of Outbreaks in Forward-Deployed Military Units.**
  - **The Concept of Epidemiological Surrogates for Diseases Like Pneumonic Plague and Smallpox Is Currently under Investigation. This Is to Suggest That Analyses of Common Respiratory Disease Outbreaks in Military Populations Could Yield Meaningful Surrogate Transmission Rates.**

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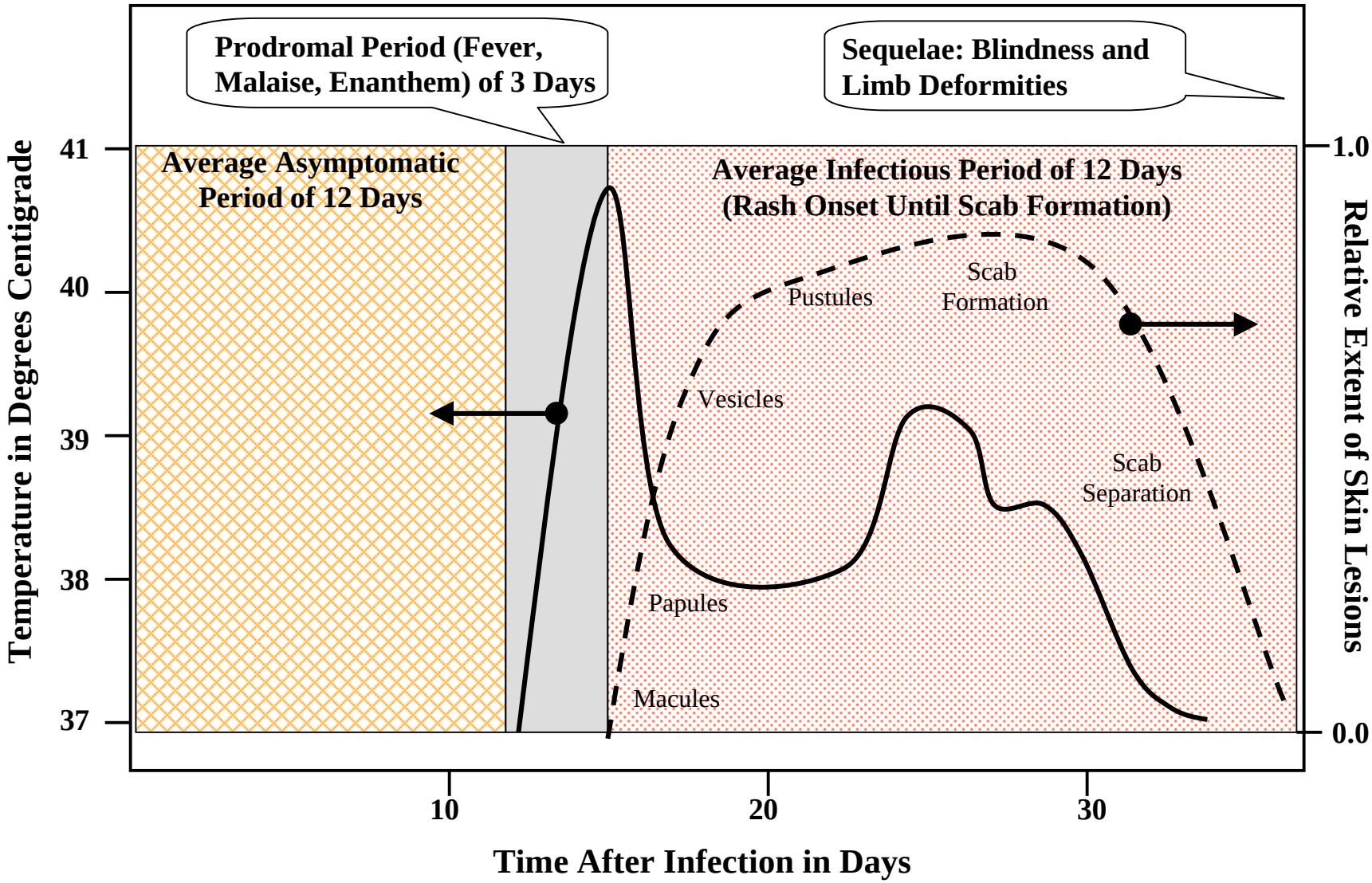
General Concerns about Smallpox

- **From Antiquity Until Its Worldwide Eradication, Smallpox Was Regarded as a Severe Contagious Disease with a Substantial Fatality Rate (Many Millions of Deaths in the 20th Century)**
- **The FSU Reportedly Weaponized the Smallpox (Variola Major) Virus and Maintained a Large Stockpile**
- **Today's Young Adults Haven't Been Vaccinated Against Smallpox, and Few of Today's Physicians Have Ever Treated a Smallpox Case**
- **The Live Vaccinia Virus Vaccine Can Provide Effective Protection If Administered Before or Soon After Exposure, But the Timely In-Theater Utilization of Vaccine Stocks Could Be Problematic**

Clinical Features of "Ordinary" Smallpox



Relevance of the Last European Smallpox Outbreaks

- **By 1953, Smallpox Was Not an Endemic Disease in European Countries Because of Comprehensive Vaccination Programs**

- **European Smallpox Outbreaks Still Occurred in the 1950s, 1960s, and the Early 1970s, But These Outbreaks Were Often Linked to: (a) Travelers Who Were Infected Elsewhere (Pakistan, Indonesia, etc.), and (b) Fewer Vaccinations of European Adults**

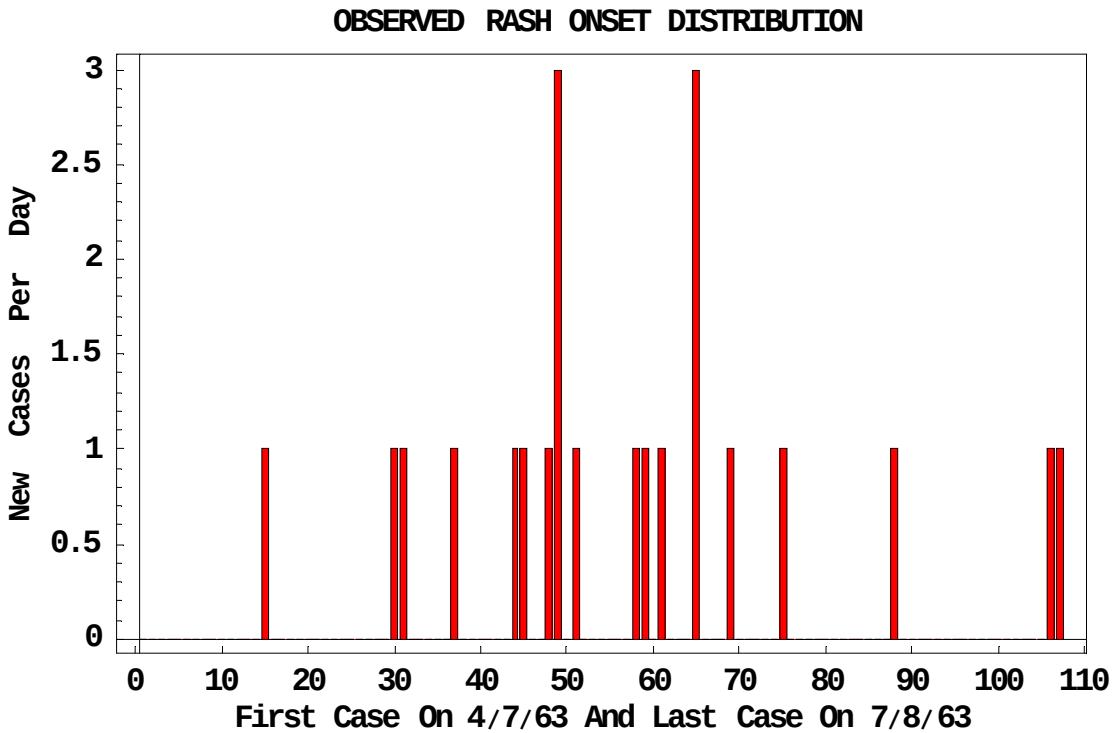
- **Epidemiological Circumstances that Surrounded the Last European Smallpox Outbreaks May Be Qualitatively Similar to Those Surrounding a Future BW or Bioterrorism Event**
  - **Disease Awareness & Medical Response Time**
  - **Disease Transmission Factors**
  - **Medical Treatment Capabilities & Patient Isolation Procedures**
  - **Outbreak Controls (E.G., “Ring” or Other Vaccination Strategies)**

Selected European Smallpox Outbreaks

	Available Epidemiological Data	Epidemiological Circumstances	Modes Of Disease Transmission	Outbreak Foci	Geographical Area Of Containment
Stockholm, Sweden 1963	**Excellent**	**Vaccination Program, No Early Diagnosis Of Index Case**	**Mixed**	**Four Hospitals**	**Moderate (About 30 Square Kilometers)**
Meschede, Germany 1970	**Good**	**Vaccination Program, Index Case Diagnosis In Five Days**	**Airborne***	**Single Hospital**	**Small**
Yugoslavia 1972	**Good**	**Vaccination Program, No Early Diagnosis Of Index Case**	**Mixed**	**Several Medical Facilities**	**Very Large (About 50,000 Square Kilometers)**

*** Infectious Aerosol & Disease Transmission At Distances Of 10 Meters Or More**

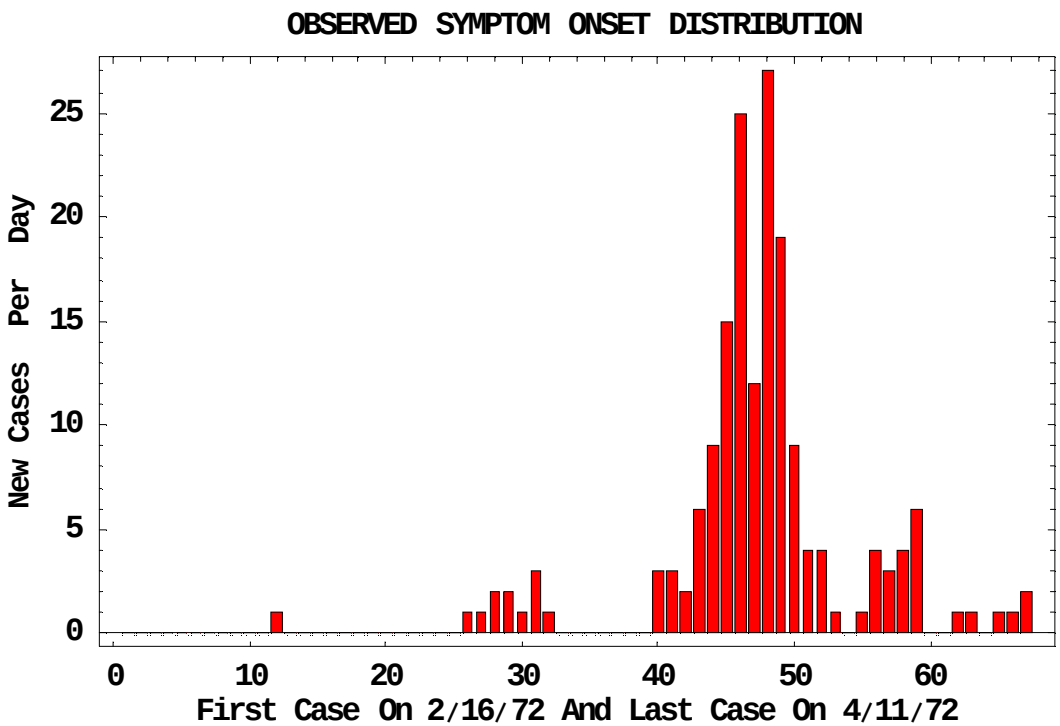
1963 Smallpox Outbreak in Stockholm & Input for Lower-Bound Analyses



Note: The Above Rash Onset Data Does Not Account for 1 Case of Abortive Variola, 3 Cases of Variola Sine Eruptione, and 1 Case of Variola Asymptomatica.

- **Last Swedish Case of Smallpox Was in 1932**
- **Circumstances Surrounding 1963 Stockholm Outbreak**
  - **Susceptible Population**
  - **Delayed Diagnosis**
  - **Infections Among Health Care Workers (27% of All Secondary Infections)**
  - **Infections Among Hospital Patients (27% of All Secondary Infections)**
  - **Long Vaccination Program**
- **Case-Fatality Rate for 1963 Stockholm Outbreak**
  - **Overall Rate of 15%**
  - **2 of the 3 Previously Unvaccinated Cases Resulted in Death**

1972 Smallpox Outbreak in Yugoslavia & Input for Upper-Bound Analyses



- Last Yugoslavian Case of Smallpox Was in 1927
- Circumstances Surrounding 1972 Yugoslavian Outbreak
  - Susceptible Population
  - Delayed diagnosis
  - Nosocomial Transmission (48% of All Infections)
  - Unsuccessful Revaccination (Liquid Vaccine Problems)
  - Communication Problems in Tracing Exposed People
  - Unusually High Proportion of Hemorrhagic Cases (10% Vice the Typical 1%)
- Case-Fatality Rate for 1972 Yugoslavian Outbreak
  - Overall Rate of 20%
  - Rate for the Unvaccinated Twice That for the Previously Vaccinated

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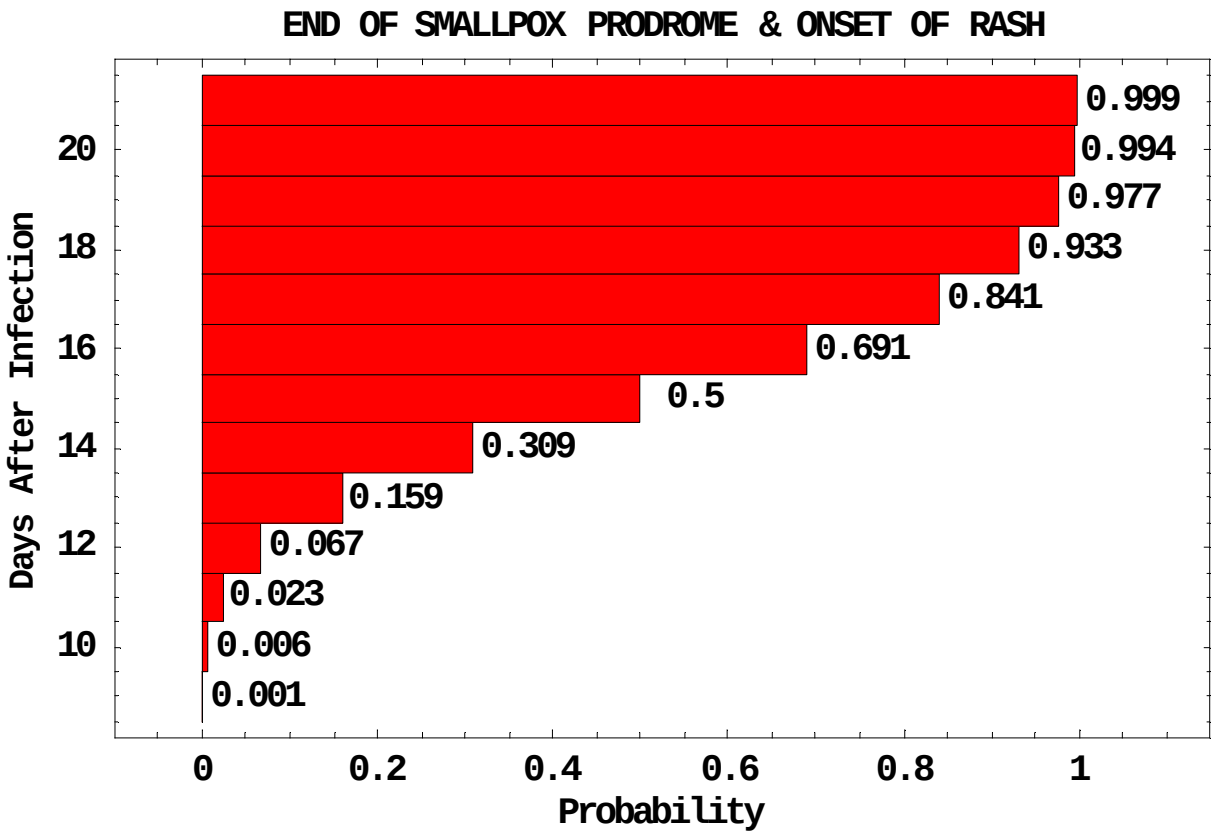
Smallpox & Scenario B

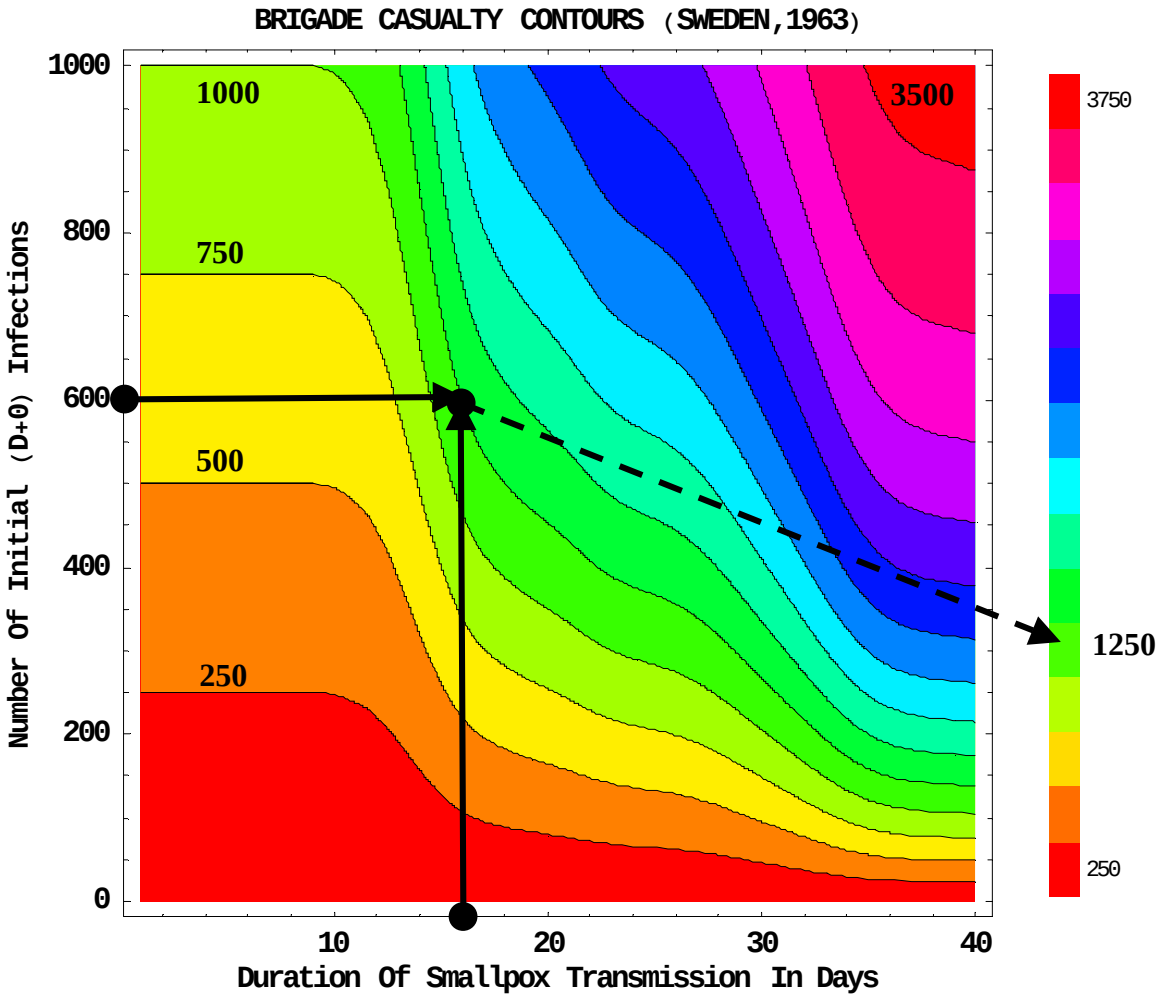
- **No Pre-Attack Smallpox Vaccinations**
- **No Trans-Attack Respiratory Protection**
- **No Prompt Post-Attack Identification of Aerosolized Variola Virus**
- **Upon Lab Confirmation of First Smallpox Diagnosis, One-Day Smallpox Vaccination Program Covers Entire Brigade, Division or Corps**
- **Isolation/Quarantine Prevents Smallpox Transmission Beyond Vaccinated Military Population**

Time Frame from Day of Infection to First Lab Confirmation of Smallpox Infection?



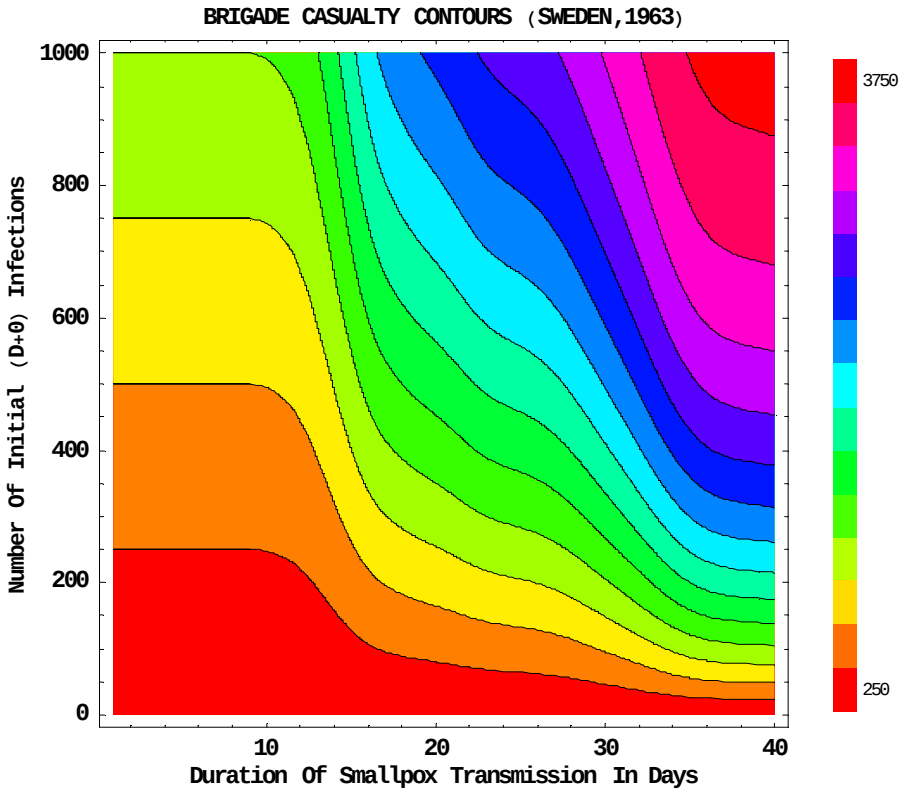
Note: The Above Graph Is Based upon a Combined Incubation Period and Prodrome that Is Characterized by a Normal PDF with a Mean of 15 Days and a Standard Deviation of 2 Days. For 1000 Initial Infections, this Graph Indicates there Would Be 1 Infected Person with a Rash After 9 Days, 6 People with Rashes After 10 Days, 23 People After 11 Days, Etc.

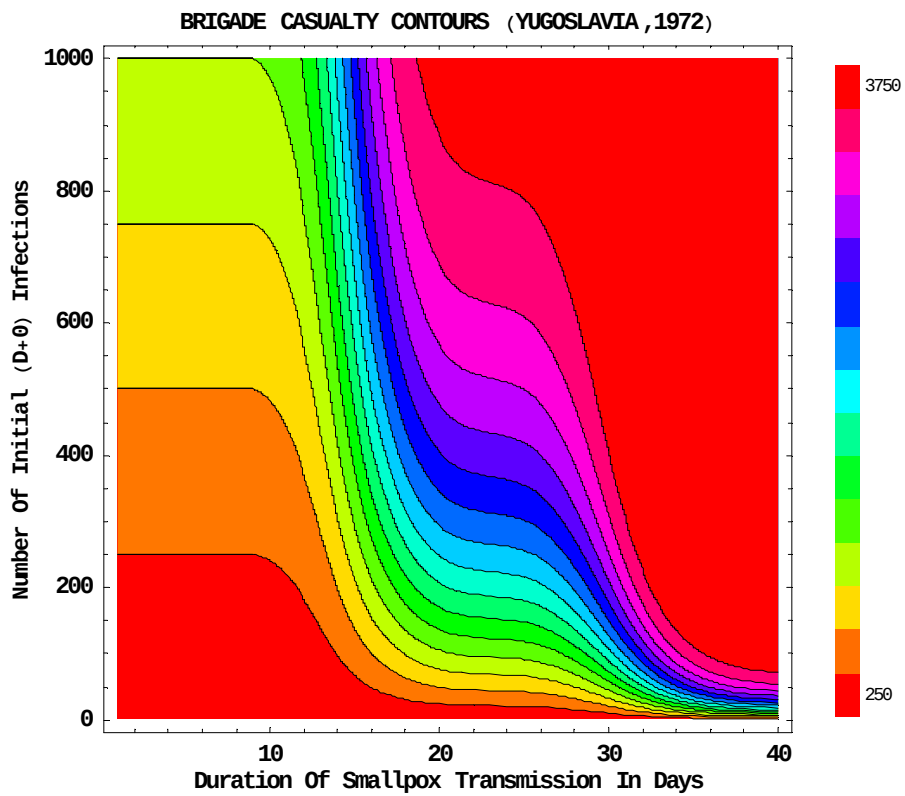
Smallpox Casualty Contour Plots: An Illustration Of Usage



- The X-Axis in Smallpox Casualty Contour Plots Defines the Day Number (D+T) when Disease Transmission Ends (E.G., Because of Vaccinations).
- The Y-Axis Defines the Number of D+0 Infections Due to a Smallpox Attack on an Initially Isolated Military Unit (E.G., Brigade).
- Suppose <u>Both</u> the Number of D+0 Infections (E.G., 600) and the Duration of Smallpox Transmission (E.G., 16 Days) Are Known. Then the Casualty Contour Plot Provides A "Point" Casualty Estimate (E.G., 1250).
- Casualty Contour Plots Can Also Be Used in Other Ways.

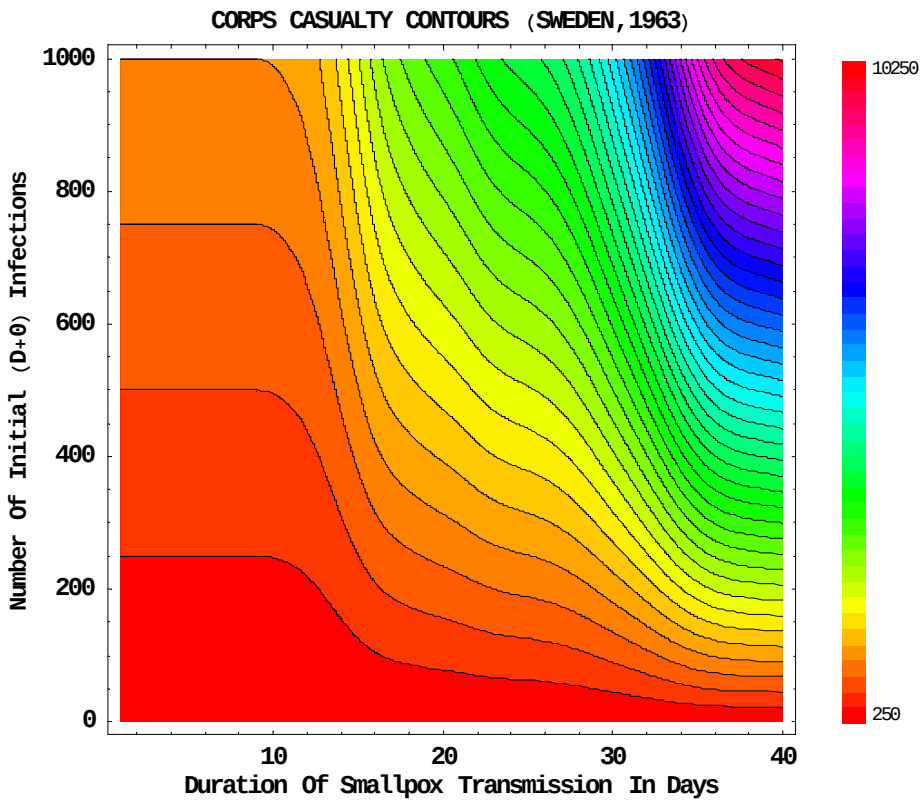
Smallpox Casualty Calculations for the Brigade in Scenario B

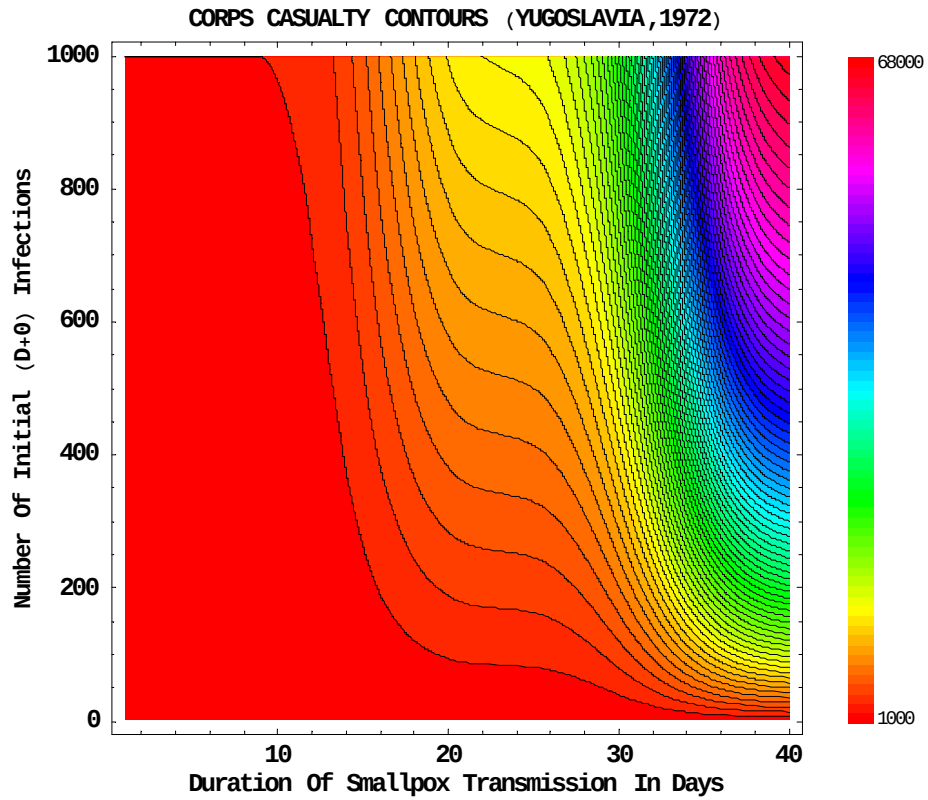




<u>Note</u>: Since a Completely Successful Vaccination Program Occurs on D+τ, the Duration of Smallpox Transmission Cannot Exceed τ. For this Reason, Values Along the X Axis in the Above Graphs Are Values of τ.

Smallpox Casualty Calculations for the Corps in Scenario B





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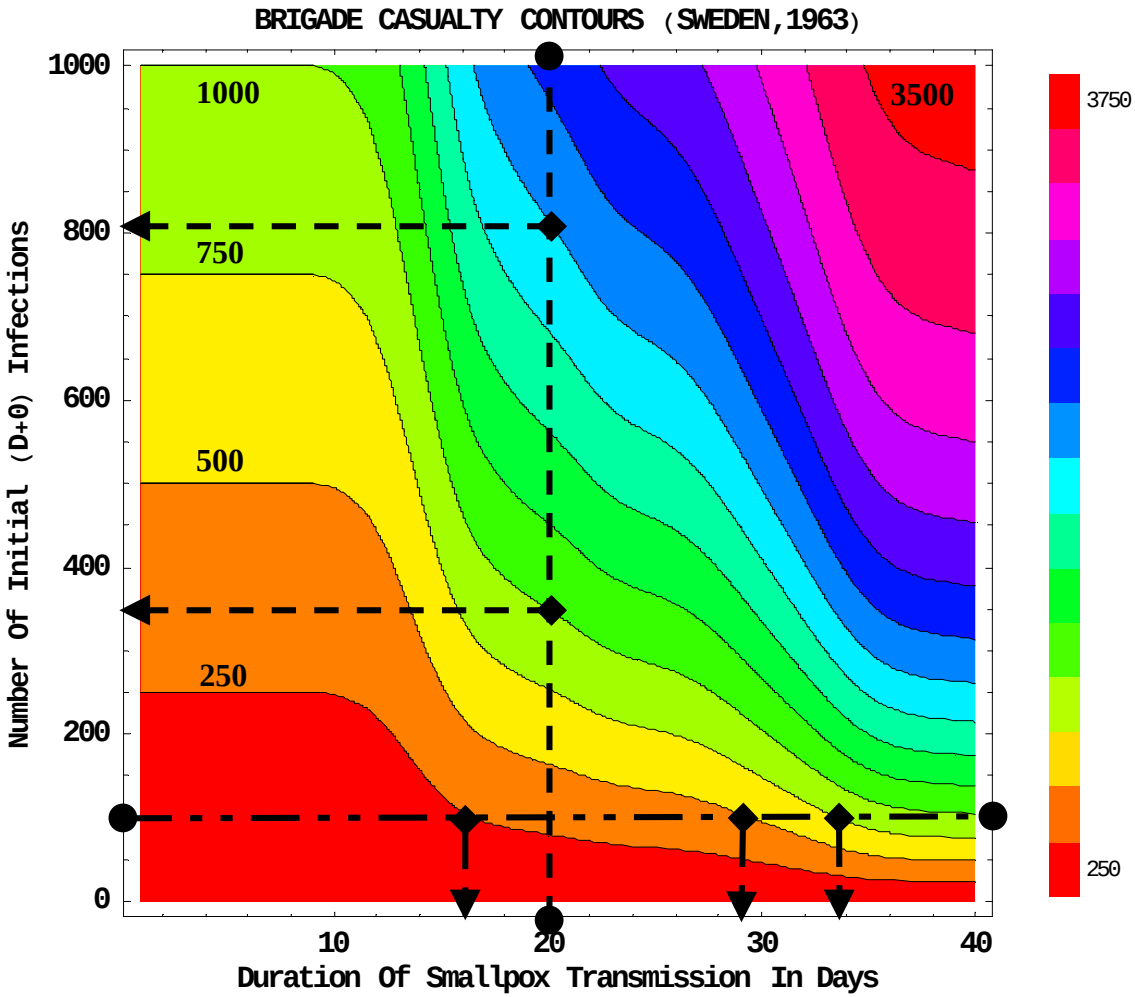
Concluding Comments

- **Semi-Empirical Casualty Estimates for Scenarios A, B and C Elucidate Both Benefits of Major Defensive Capabilities and Consequences of Critical Defensive Deficiencies. These Estimates Should Also Help Health Care Planners Put Proposed or Existent BW/BT Medical Requirements in the Context of Historical Outbreaks.**

- **To Be Sure, Scenarios A, B and C Are Not the Only Interesting or Analyzable Situations. For Instance, Quarantine Relaxation Effects (in the Midst of a Pneumonic Plague Outbreak) Are Presently under Investigation.**

Backups

Smallpox Casualty Contour Plots: An Illustration Of Usage



- **The X-Axis in Smallpox Casualty Contour Plots Defines the Day Number (D+T) when Disease Transmission Ends (E.G., Because of Vaccinations).**
- **The Y-Axis Defines the Number of D+0 Infections Due to a Smallpox Attack on an Initially Isolated Military Unit (E.G., Brigade).**
- **If the Number of D+0 Infections Is Known (E.G., 100), Then the Casualty Contour Plot Provides Casualty Estimates (E.G., 250, 500 and 750) for Various Periods of Disease Transmission (16, 29 and about 34 Days, Respectively).**
- **On the Other Hand, If D+0 Infections Are Unknown and There Is a Planned Vaccination Day (E.G., D+20), Then the Casualty Contour Plot Provides Casualty Estimates (E.G., 1000 and 2000) for Various D+0 Infections (350 and about 800, Respectively).**